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*A DETERMINATION OF THE SOLAR MOTION AND THE STREAM
MOTION BASED ON RADIAL VELOCITIES AND
ABSOLUTE MAGNITUDES*

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In previous determinations of the motion of the sun in space and of the star streams the stars have been divided for discussion according to spectral type or apparent magnitude. The recent investigations of Adams and Strömberg¹ have shown that the intrinsically faint stars have a higher average radial velocity than those that are intrinsically brighter, or in other words, that radial velocity is a function of absolute magnitude. Accordingly an investigation of the solar motion and the stream motion based upon a division of stars into groups of nearly equal absolute magnitude is of exceptional interest, since the dispersion of the radial velocities within each group is considerably less than in the usual case. A brief account of such an investigation is given in this communication.

Of the 1300 stars of the spectral types F, G and K with measured radial velocities which have been used in the discussion, about 700 have absolute magnitudes determined spectroscopically by Adams. For the remainder, observed mainly at the Lick and Mills Observatories, mean parallaxes have been computed by the aid of the following formula connecting proper motion and apparent magnitude:

$$\log \pi = \log A + \log (\mu + c) + m \log \epsilon,$$

in which π is the mean parallax, μ the proper motion, m the apparent magnitude, and A , c and ϵ constants determined by means of the spectroscopic parallaxes. The formula differs from that of Kapteyn,² which for later type stars of very small proper motion gives parallaxes that are too small, in the addition of the constant c .

Solar Motion.—The constants of the solar motion have been determined by a least squares solution of equations of condition of the form

$$V = x_0 \cos \alpha \cos \delta + y_0 \sin \alpha \cos \delta + z_0 \sin \delta + K,$$

in which V is the radial velocity, $-x_0$, $-y_0$, and $-z_0$ the rectangular components of the sun's motion, and K Campbell's K -term, the quantity which must be subtracted from each of the radial velocities, corrected for the sun's motion, in order to make their sum equal to zero. The results indicate that the K -term has a small positive value in the case of the very luminous stars, and probably a negative value in the case of the fainter stars. For K equal to

zero the constants of the solar motion have the values given in table 1. \bar{M} and \bar{m} are the arithmetical means of the absolute and apparent magnitudes, A and D the right ascension and declination of the sun's apex, V_0 the sun's velocity in space, and ϑ the arithmetical mean of the radial velocities corrected for the sun's motion, taken regardless of sign. The results given by the groups of faintest magnitude are necessarily uncertain since the stars included within them are almost exclusively in the northern hemisphere and the distribution is relatively unfavorable.

TABLE 1
CONSTANTS OF SOLAR MOTION ($K = 0$)

NO.	\bar{M}	\bar{m}	A	D	V_0	ϑ
<i>F and G type stars</i>						
211	0.31	4.68	251°4	+22°5	km. 19.4	km. 11.3
177	1.44	5.42	267.5	+36.3	16.6	14.6
167	2.76	5.27	272.1	+36.4	22.8	16.3
170	5.29	6.41	(279.6)	(+10.9)	(27.1)	(23.9)
725	2.32	5.40	268.3	+26.1	20.1	17.2
<i>K type stars</i>						
122	0.54	4.22	279°6	+33°8	24.0	13.7
245	1.41	4.86	268.1	+37.2	20.4	16.6
99	2.58	5.12	284.5	+20.1	26.0	18.6
79	7.07	7.41	(289.0)	(+26.5)	(22.1)	(26.2)
545	2.25	5.13	277.0	+32.5	22.2	18.5
<i>M type giants</i>						
135	1.5	4.98	264°2	+26°1	26.8	16.9

All stars of late type

$$\begin{aligned}
 A &= 270^\circ 9 \pm 3^\circ 3 & D &= + 29^\circ 2 \pm 3^\circ 4 & V_0 &= 21.48 \pm 1.02 \text{ km} \\
 \vartheta &= 17.7 \text{ km} & K &= + 0.36 \pm 0.60 \text{ km}
 \end{aligned}$$

There appears to be a tendency toward smaller values of the declination for the intrinsically faint stars. If real this effect may be explained on the assumption of a variation in the proportion of stars belonging to the two star drifts. A marked feature of the results is the increase of the average radial velocity with decreasing brightness.

Stream Motion.—For a study of stream motion the stars with measured radial velocities have been divided into three groups, as follows, according to absolute magnitude:

GROUP	NO.	\overline{M}	\overline{m}	π	ϑ
					<i>km.</i>
I	509	0.76	4.83	0".015	13.11
II	513	2.08	5.09	0.025	17.13
III	260	6.05	6.82	0.070	25.88

Each group contains stars of spectral types F, G and K, the third group, comprising the faintest stars, also including 11 stars of the dwarf M type. The symbol π denotes the geometrical mean of the parallaxes, which is readily derived by the formula

$$5 \log \pi = M - m - 5.$$

In accordance with the method of Charlier, the sky has been divided into 48 equal areas situated symmetrically with reference to the galactic equator. If star streaming is studied on the basis of the ellipsoidal or the two drift theory, opposite areas may be combined by assuming that the stream motion is the same in all parts of the space.

Since the sun, however, is not situated at the center of the stellar system, but at a distance from it probably comparable with the mean distance of the later type stars used in this investigation, we might, according to the theory of Turner³ and Eddington,⁴ conceive the stream-motion to be due to the general attraction of the stellar system. It would then differ from point to point and be related to the position of the center and the central plane of the stellar system. Such a theory is supported by Kapteyn's⁵ suggestion that there is an acceleration of the first stream; i.e., that the velocity of the first stream is different in different parts of the space.

In order to test for the existence of such a varying stream-motion, I have tried to express the average radial velocity as a rational integral function of the direction-cosines of the line of sight such that the radius vector of the surface thus defined equals the average radial velocity. Using only terms of second order we can in this way determine the stream-motion, if the latter is constant (Eddington⁶). If the stream motion is variable this must be marked by the existence of asymmetrical (odd) terms in the analytical representation of the surface.

In this investigation terms to the third order inclusive have been determined.

If terms of the second order alone are included, opposite areas in the sky may be combined. The resulting directions of the axes of maximum radial velocity θ are thus:

GROUP I			GROUP II			GROUP III		
ϑ	α	δ	ϑ	α	δ	ϑ	α	δ
<i>km.</i>			<i>km.</i>			<i>km.</i>		
16.14	98°	+5°	20.98	86°	+10°	32.4	100°	+34°

The position found for the axes of preferential motion is in good agreement with other determinations which, according to the summary by Eddington, give $\alpha = 94^\circ$, $\delta = +12^\circ$.

The asymmetrical terms, or those of odd order, are next determined separately for the three groups. If those which depend only on the galactic latitude are considered, we obtain expressions for θ from which the following maximum values may be derived:

GROUP I		GROUP II		GROUP III	
ϑ	b	ϑ	b	ϑ	b
km.		km.		km.	
13.9	$-19^\circ 1$	19.7	$-19^\circ 9$	28.4	$-22^\circ 8$

We find, accordingly, in all cases a negative latitude for the maximum θ . It is known, however, that the sun is situated north of the real galactic plane, the distance being about 20 parsecs,⁷ or a distance corresponding to a parallax of 0".05. This indicates a maximum of motion, not in the galactic equator, but in the real galactic plane. The form of the surface for the second group is shown in figure 1.

The surfaces which represent the average radial velocity for the first and second groups are very nearly the same, the most important features being two large terms of second and third order. These are as follows, b and l being the galactic latitude and longitude, respectively:

	SECOND ORDER	THIRD ORDER
Group I	$2.59 \cos^2 b \cos 2 (l - 174^\circ 3)$	$2.90 \cos^3 b \cos 3 (l - 76^\circ 0)$
Group II	$3.18 \cos^2 b \cos 2 (l - 162^\circ 7)$	$3.10 \cos^3 b \cos 3 (l - 77^\circ 6)$

The second order terms define the stream motion, and the existence of the large third order terms shows that the axes of maximum radial velocity do not lie in a straight line.

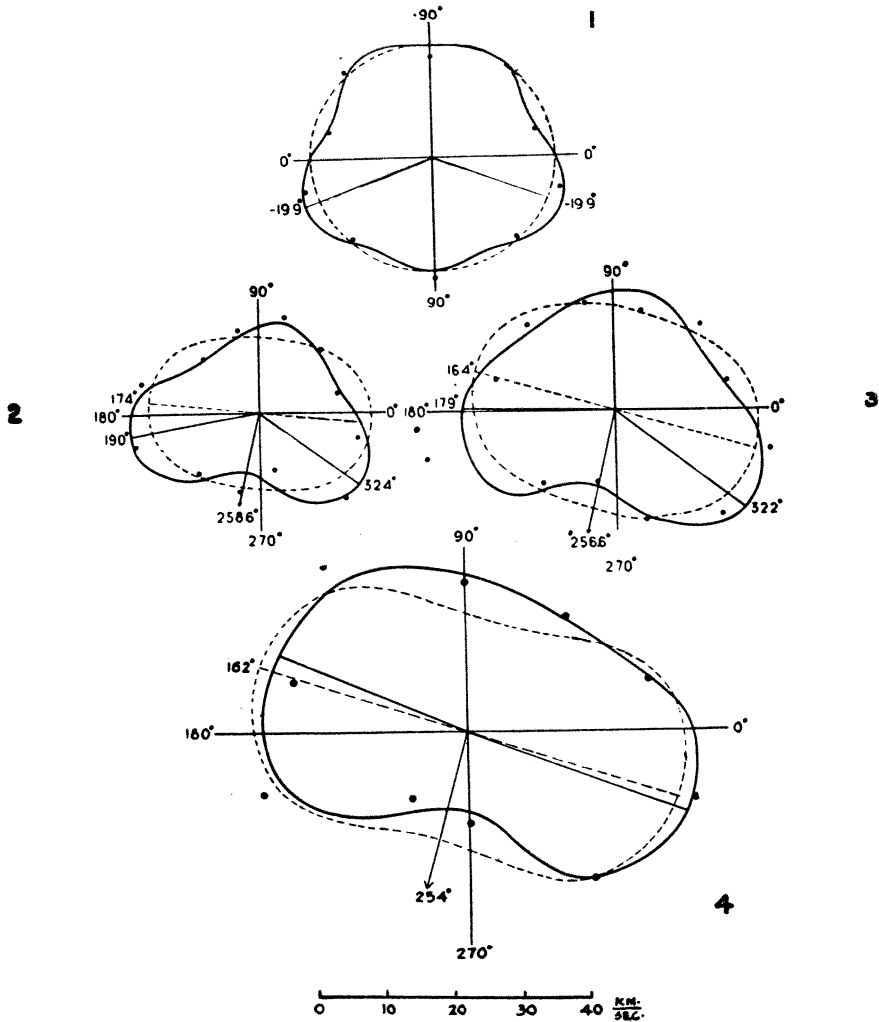
The two principal maxima of θ in the two surfaces are

	ϑ	l	b	α	δ	ϑ	l	b	α	δ
	km.					km.				
Group I	19.60	190°	$+ 4^\circ$	109°	-7°	17.50	324°	$- 2^\circ$	264°	-33°
Group II	24.23	179	-18	84	-7	26.33	322	-19	283	-41

We find, therefore, that the axes of largest radial mobility, which may be assumed to correspond approximately to the direction of preferential motion in space, form obtuse angles equal to 134° and 128° , respectively, for the two

groups, and that there is a pronounced minimum at longitude 258° . The nearest approach to a symmetrical plane at right angles to the galactic plane has the longitude

258.6° for Group I and 256.6° for Group II.



In figures 2 and 3 are shown the intersections between the radial velocity surfaces and the galactic equator. The dotted curves indicate the intersections when only terms of even order are considered, and the arrows mark the position of the symmetrical planes.

The properties of these surfaces may be explained on the assumption that

the motions of the stars depend upon their positions relative to the center of the galactic system. According to Charlier³ the position of the center as derived from 800 B-type stars is

$$l = 236^\circ \quad b = -14^\circ \quad \text{Distance} = 88 \text{ parsecs.}$$

O. R. Walkey⁸ finds from 30736 stars of all types the longitude $l = 246^\circ$. These values of the galactic longitude of the center of the stellar system are in fair agreement with the value 258° found for the position of the symmetrical plane. We may, therefore, conclude that the variation of average radial velocity with direction is due probably to a motion of the stars around the center of the galactic system. Moreover, if the stars are moving around the center of the stellar system we should expect a minimum orbital velocity near the center and a maximum at a certain distance from the center.⁵ The minimum in radial velocity near longitude 268° is in agreement with this conclusion.

In the case of the stars nearest to us, we should expect the axes of preferential motion to lie nearly in a straight line, since their distance from us is small as compared with their distance from the center.⁹ To test this question I have made an analysis of the radial velocities of the stars in Group III, which contains the nearest stars, combining all stars between galactic latitudes -66° and $+66^\circ$. The axes of maximum radial velocity for the resulting curve have the longitudes 157° and 340° , which thus differ by 183° . The longitude of the axis of symmetry is 254° , a value in good agreement with that found for the more distant stars. The intersection of the surface with the galactic plane is shown in figure 4.

The conclusion to be drawn from these results is that stream motion is probably a local effect caused by a preferential motion of the stars in both directions around the center of the stellar system. This might have been expected from the fact that the motions of the two 'drifts' have been found to be in the galactic plane and at right angles to the direction of the center of the galaxy. The deviation of the axes of preferential motion from a straight line furnishes strong evidence in support of this conclusion.

¹ Adams, W. S., and Strömberg, G., *Mt. Wilson Contr.* No. 131, *Astroph. J.*, Chicago, **45**, 1917, (293-305).

² Kapteyn, J. C., *Groningen, Pub. Astr. Lab.*, No. 8.

³ Turner, H. H., *Mon. Not. R. Astr. Soc. London*, **72**, 1912, (387-407).

⁴ Eddington, A. S., *Ibid.*, **75**, 1915, (366-376).

⁵ Mt. Wilson Solar Observatory, *Annual Report*, 1916, (255).

⁶ Eddington, A. S., *Mon. Not. R. Astr. Soc., London*, F. S., 1915, (521-530).

⁷ Charlier, C. V. L., *Medd. Lunds Obs., Upsala*, Ser. 2, No. 14, 1916, (31).

⁸ Walkey, O. R., *Ibid.*, **74**, 1914, (649-655).

⁹ Strömgren, E., *Astr. Nachr., Kiel*, **203**, 1916, (17-24).